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ULTRASONIC DOPPLER DIRECTIONAL BLOOD FLOW VELOCITY METER (UL'TR--ETC(U)
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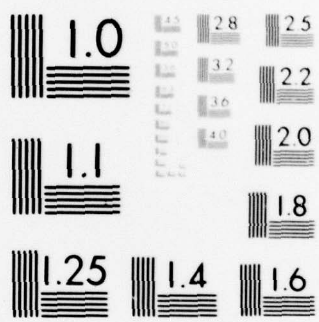

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ULTRASONIC DOPPLER DIRECTIONAL BLOOD FLOW VELOCITY METER

by

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ULTRASONIC DOPPLER DIRECTIONAL BLOOD FLOW VELOCITY METER

(UL'TRAZVUKOVOI DOPPLEROVSKII IZMERITEL SKOROSTI KROVOTOKA)

by

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L. I./Yakimenkov,
Yu. N./Gusev
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Translator
J.W. Palmer

Translation editor
J.B. Abbiss

AUTHORS' SUMMARY

An investigation is made of a principle for detecting the sense of the velocity of a blood flow using ultrasonic Doppler meters. The USD meter operates in single-frequency continuous-signal conditions with a combined piezoelectric sender/receiver.

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It is well-known to physiologists and medical men that the effect of what has been called the negative blood flow which is observed in aortic vessels may have both a physiological and a pathological origin. In this connection, an important metrological characteristic of blood flow meters in vessels is a sensitivity to the direction of flow, which makes it possible to reduce the measurement error of the linear or volumetric velocity of the blood flow, and to record the distortion-free form of the instantaneous blood velocity; *ie* it assists in correctly interpreting the process of blood circulation in the cardiovascular system on the basis of a quantitative study of the blood flow.

Ref 1 provides a block diagram of an ultrasonic Doppler (USD) instrument for the measurement of blood flow velocity, which is directionally sensitive and operates continuously at a single frequency. However, the proposed diagram is applicable to USD flowmeters, in the sensors of which the transmitting and receiving piezoelectric transducers are separated electrically or in construction.

It should also be noted that techniques for combining the transducers are available[2,3]. The advantages of combining sender and receiver include higher sensitivity and simplification of the design.

We have developed a circuit for a USD device for blood flow measurement (see Fig 1) which operates continuously at a single frequency and is sensitive to the direction of the blood flow. The circuit also makes it possible to incorporate a combined sender-receiver unit.

The signal

$$a_1 = A_1 \sin \omega t ,$$

where A_1 is the amplitude and ω the frequency, passes from the oscillator 2 to the compensator 3, the piezoelectric transducer of the sensor 4 and the detector 6.

The piezo element of the sensor 4 transforms the high-frequency electrical signal a_1 into ultrasonic oscillations and transmits them to the blood flow. The scattered signal from the moving blood (erythrocytes), shifted in frequency by the Doppler effect, falls on the piezoelectric sensor 4, which combines the functions of emitter of the ultrasonic waves and receiver of the scattered signal, and is transformed into an electrical signal

$$a_2 = A_2 \sin(\omega t \pm \omega_d t) ,$$

where ω_d is the frequency of the Doppler signal, proportional to the velocity of movement of the blood; the positive sign indicates that the blood moves towards, and the negative sign away from, the emitter.

The signal a_2 passes, as does a_1, to the compensator 3 and detector 6. For USD blood flow velocity meters, $A_1 \gg A_2$.

In order to simplify the calculations it may be assumed that all erythrocytes move with identical velocity.

For operation of the piezo-transformer under linear conditions the occurrence of the two signals in the system may be expressed in terms of a beat frequency[4,5]:

$$G_1 = a_1 + a_2 = A_1 \sin \omega t + A_2 \sin(\omega t \pm \omega_d t)$$

$$= \sin \omega t(A_1 + A_2 \cos \omega_d t) + \cos \omega t A_2 \sin(\pm \omega_d t) \quad . \qquad (1)$$

Let us put

$$\begin{aligned} A_1 + A_2 \cos \omega_d t &= V(t) \cos \psi(t) \; , \\ A_2 \sin(\pm \omega_d t) &= V(t) \sin \psi(t) \quad . \end{aligned} \qquad (2)$$

Then equation (1) will assume the form

$$b_1(t) = V(t)[\sin \omega t \cos \psi(t) + \cos \omega t \sin \psi(t)] = V(t) \sin[\omega t + \psi(t)] \; . \; (3)$$

From equations (2)

$$V(t) = A_1 \sqrt{1 + \frac{A_2}{A_1} \cos \omega_d t + \left(\frac{A_2}{A_1}\right)^2} \approx A_1 \left(1 + \frac{A_2}{A_1} \cos \omega_d t\right) \; ,$$

$$tg\psi(t) = \frac{\dfrac{A_2}{A_1} \sin(\pm \omega_d t)}{1 + \dfrac{A_2}{A_1} \cos \omega_d t} \; .$$

Reverting to the expression for the intensity of the beats (3) it follows that

$$G_1(t) \approx A_1 \left(1 + \frac{A_2}{A_1} \cos \omega_d t\right) \sin[\omega t + \psi(t)] \quad . \qquad (4)$$

In order to obtain a signal at the frequency ω_d it is necessary to detect the intensity of the beats. For the conditions $\omega \gg \omega_d$ and $A_1 \gg A_2$ we can disregard the phase angle $\psi(t)$ in equation (4) so far as amplitude detection is concerned.

At the output of the square-law diode detector 6 we obtain

$$u_1 = U_1 \cos \omega_d t \quad ,$$

where $U_1 = kA_2$, k being the transmission coefficient of the detector. The signal $a_3 = A_3 \sin(\omega t + \pi)$ is passed from the oscillator 2 to the phase transformer 1 and the compensator 3.

Thus, the following signals reach the input of the square-law detector 5: $a_3' = A_3 \sin(\omega t + \pi/2)$ from the phase-transformer 1, $a_2 = A_2 \sin(\omega t \pm \omega_d t)$ and $a_1' = A_1' \sin \omega t$ (uncompensated a_1) from the compensator 3. These signals may be represented in beat form. By using the conditions that $A_3 \gg A_1' \gg A_2$ and $\omega \gg \omega_d$, and by making appropriate trigonometric transformations, we obtain:

$$b_2(t) = a_3' + a_2 + a_1' = A_3\left[1 + \frac{A_2}{A_3}\cos\left(\omega_d t \pm \frac{\pi}{2} - \frac{\pi}{2}\right)\right]\sin \omega t + A_1' \sin \omega t \qquad (5)$$

The first component in equation (5) includes information about the Doppler signal, from the beating of the two signals a_3' and a_2 , whereas the second component a_1' arises from non-compensation of the signal a_1 in the compensator 3. Its effect may be eliminated by selecting an appropriate bias for the detector 5, so that on the output load of the latter we obtain a signal

$$u_2 = U_2 \cos(\omega_d t \mp 90^\circ - 90^\circ) \quad ,$$

where minus (before 90°) appears for $+\omega_d t$ and plus appears for $-\omega_d t$. The signals u_1 and u_2 pass via low-frequency amplifiers 7 and 8 to the Schmitt triggers 9 and 10 and subsequently to the balanced phase-detector 11, the output voltage of which is

$$U_f = 2k_f U\left(\left|\cos \frac{\varphi}{2}\right| - \left|\sin \frac{\varphi}{2}\right|\right) \quad ,$$

where k_f is the transformation coefficient of the detector, U is the amplitude of the signals arriving from the triggers and φ is the phase difference of the signals fed to the detector 11.

Thus, at the output of the phase-detector there appears a voltage $U_{f1} = -2k_f U$ for $+\omega_d t$ and $U_{f2} = 2k_f U$ for $-\omega_d t$.

By means of these voltages the gate circuits 12 and 13 may be controlled and the appropriate signal passed to the frequency meters 14 and 15; the output voltage of one of these will then be proportional to the velocity of motion of the blood flow in one direction, and that of the other to the velocity of motion of the flow in the opposite direction.

The technical data for the blood flow meter are as follows: emission frequency 5.6 MHz, emission intensity not exceeding 0.05 W/cm^2, range of measured velocities 0-150 cm/s, effective error not exceeding ±6%.

Fig 2 shows examples of recordings, together with electrocardiograms, of the measured velocity of the blood flow in the ascending aorta of a dog, which was obtained by means of an ultrasonic Doppler velocity meter (a) without directional separation and (b) with directional separation. The principle of directional separation may be used in USD probes for studies of the heart, foetus and other objects moving in sound-conducting media.

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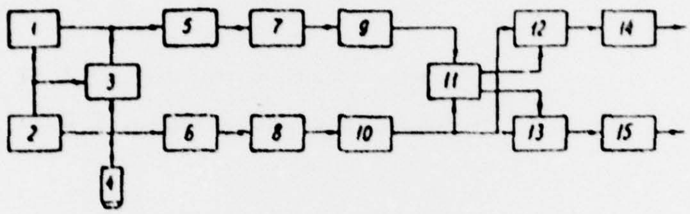
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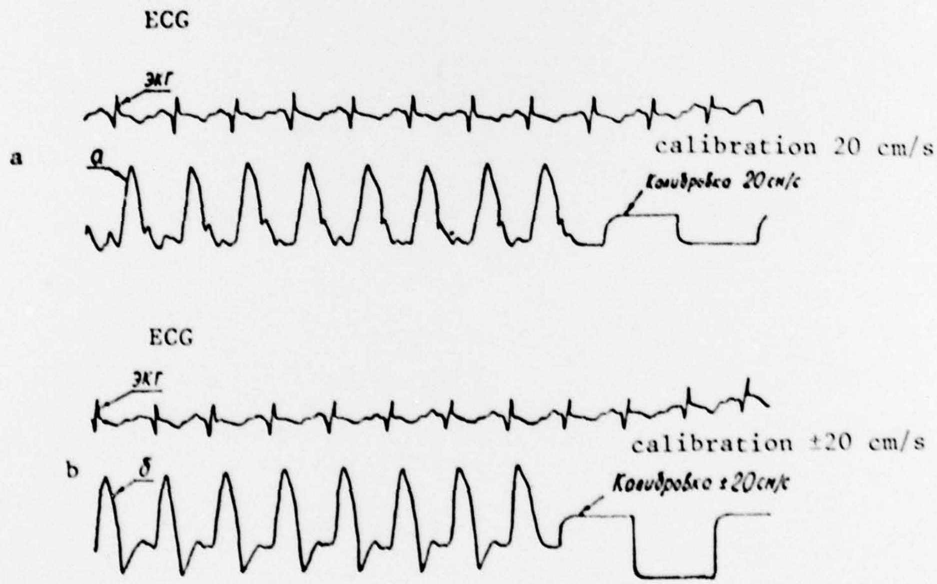
Fig 1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a
calibration 20 cm/s
ECG
ЭКГ
b
calibration ±20 cm/s

Fig 2

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